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The Role of Habituation and Sensitization in Understanding the Annoyance of Community Exposures to Impulsive Noise

George A. Luz and Edward T. Nykaza

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Abstract: Military personnel must consider the effect of the noises their activities produce. Understanding and predicting how people react to such common military noise as gunfire or explosive blasts is important, since nearby civilian populations and their opinions of military operations can affect future military operations and facility expansions. The problem this report addresses is determining those factors which are the best predictors of whether someone will be annoyed by noise. To better select the most valuable predictors for annoyance to military noise, a review of published international studies on the subject was done. One possible predictor is a physiological process known as "habituation," in which the brain stops responding to repeated stimuli. This review then goes beyond habituation to include the roles of the dual process theory and individual sensitization, both of which can influence reported annoyance. This work concludes with recommendations of what military planners and their research teams should consider in order to obtain the most reliable results from future studies of annoyance to military noise. Those recommendations include specific suggestions for designing new surveys that better explain relationships between individual characteristics or situations, and the same individual's annoyance to noise.

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Preface

This report is a deliverable product resulting from research conducted under Department of the Army project A896, “Base Facilities Environmental Quality,” Work Unit 33143, “Training and Testing Range Noise Control,” funded by the U.S. Army Corps of Engineers. This report was reviewed and approved by the Army’s designated Technical Monitor for Training and Testing Range Noise Control, Catherine Stewart, USA CHPPM (United States Army Center for Health Promotion and Preventive Medicine) Operational Noise Program.

The work was performed by the Ecological Processes Branch (CN-N) of the Installations Division (CN), Construction Engineering Research Laboratory (CERL). The CERL Principal Investigator was Edward T. Nykaza. Alan B. Anderson is Chief, CN-N, and Dr. John T. Bandy is Chief, CN. The associated Technical Director was Dr. William D. Severinghaus, CVT. The Deputy Director of CERL is Dr. Kirankumar V. Topudurti, and the Director of CERL is Dr. Ilker Adiguzel.

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Unit Conversion Factors

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1 Introduction

Background

Under the provisions of the National Environmental Policy Act of 1969, commanders in charge of the operation of U.S. Army firing ranges are obliged to do their best at deciding how changes and improvements to those ranges will affect the health and welfare of people living nearby. To provide the environmental staffs of those Commanders with the knowledge needed to assess one aspect, outdoor noise, CERL maintains the only U.S. center for research into community response to the sound of weapons and other explosions. This program, which originated in 1972, seeks to integrate information generated by its own Principle Investigators with published information from researchers studying similar issues in Australia, Germany, Japan, the Netherlands, Norway, Sweden, Switzerland and the U.K.

The impetus for the current study arose from a retrospective analysis of three social surveys of the annoyance of firing range noise, published by the Institute for Noise Abatement in Düsseldorf, Germany, more than two decades ago.

The first survey documented the annoyance experienced by residents living in the vicinity of five small arms ranges. In the original report (Buchta et al. 1982), the investigators employed a principle components factor analysis developed by the software firm SPSS, Inc. of Chicago. From applying a varimax rotation on the responses of 402 interviewees to 71 questions (variables), they arrived at four factors which, in combination, can be used to predict the subjective annoyance reported by interviewees concerning the noise from small arms: (1) excitability/arousal, (2) the frequency of disturbance, (3) a factor combining noise sensitivity with habituation (*Gewöhnung*), and (4) satisfaction with the neighborhood, environment, and quality of life.

These same data were later published in English with a slightly different statistical analysis (Buchta 1990). In the revised analysis, the number of variables was reduced to 51, and the number of interviewees was reduced to 392. The results of a different nonlinear principal components analysis (specifically, PRINcipal Components analysis by Alternating Least, or

PRINCALS) showed “that the subjective effects of the shooting sounds could be reduced to one overall psychological dimension with high negative loadings of object and subject-related annoyance, and high positive loadings of habituation to the impulse sounds.” In this case, “habituation” was defined by the interviewees’ subjective opinions on their ability to adapt to noise.

The second survey (Buchta et al. 1986) is only available in German, but has been interpreted by report co-author Dr. George Luz, who read the original report in German. The survey documented the annoyance experienced by 421 interviewees living in the vicinity of five troop training areas (each of which supported training with large weapons). At least 80 people were interviewed at each training area, and each person was queried about their annoyance over the noise from heavy weapons, helicopters, military aircraft, small arms fire, tracked vehicle traffic, and military truck traffic.

In contrast to the earlier study that was focused exclusively on small arms range noise, this study determined that habituation turned out to be a weak variable. Habituation did not emerge as one of the nine factors underlying annoyance, and it appeared only marginally in a multiple correlation, based on a subset of 23 questions chosen to measure the global annoyance from all five types of military noise sources. In that multiple correlation, the major contribution to annoyance was from the C-weighted fast level of the average weapons blast (41% of the variance), the second from the interviewees’ attitudes toward the training area (18% of the variance) and the third from self-reported ability to habituate to noise (3% of the variance).

The third survey, also only available in German, documented the experience of 246 interviewees living around the major weapons training area of U.S. Army combat units during the height of the Cold War – Grafenwöhr, Germany (Buchta 1988). This survey sought to improve upon the earlier study of large weapons noise by using a computer program to calculate contours of the annual average (daytime) weapons noise exposure (both in terms of A-weighting and C-weighting) in the communities from which the interviewees had been chosen.

When the Buchta team combined the six best predictors of annoyance into a multiple correlation, ability to habituate to noise proved to explain the largest amount of variance. For global annoyance, readiness to habituate explained 27% of the variance whereas the yearly average daytime C-weighted average sound level explained only 9% of the variance (Buchta 1988, 121, cf. Table 8.1.0-1).

A more recent demonstration of habituation comes from an *in situ* study of simulated sonic booms conducted by a research team from NASA-Langley (McCurdy et al. 2004). The purpose of the study was to determine whether equal energy metrics provided accurate annoyance predictions for exposures to different numbers of booms each day.

A digital audio system was employed for 8 weeks in each of 33 homes. Each day from 4 to 63 sonic booms were played as the test subject went about normal activities. At the end of each day, each subject was asked to rate the annoyance of all the booms heard during the day, using a scale of 0–10. Among other findings, the authors (McCurdy, Brown, and Hilliard 2004, 116:1582) concluded that, "The test subjects were more annoyed by a given sonic boom exposure occurring in the first few days of the test period than the same exposure occurring later in the test period."

Contrasting with the role of habituation in predicting the annoyance of impulsive sounds, are findings from studies of annoyance of other types of noise. Weinstein tracked the annoyance of dormitory noise among 155 college freshmen over their first two semesters (Weinstein 1978). Noise-sensitive students became increasingly disturbed during the year ($p<.01$), whereas noise-insensitive students showed no change. In a later study of community noise, Weinstein further argued for the theory that adaptation does not occur (Weinstein 1982).

Authors of other studies agreed. In a 1983 review of the annoyance of railroad noise, De Jong wrote, "In summary, it can be stated that habituation to noise in general and to railway noise in particular, in the ways it has been made operational, probably hardly occurs" (De Jong 1983). Five years later, Moehler echoed the same message in regard to rail noise, writing "the question of habituation to railway noise cannot be conclusively answered from the studies analyzed" (Moehler 1988).

For highway traffic, Őhrström and Björkman tracked sleep disturbance among healthy subjects over the course of two weeks of nighttime (laboratory) exposure to heavy vehicle noise and found no reduction in physiological effects, sleep quality, mood and performance (Őhrström and M. Björkman 1988). In a 2001 review of annoyance from road traffic, Ouis declared "whether the subjects have been living in noisy areas for many years or that they have been exposed to artificial noise for less than a week, habituation ceases after only a few days at most" (Ouis 2001).

Objective

It is noteworthy that Buchta and colleagues found habituation to be important for understanding the annoyance from gunfire noise, in view of the almost universal dismissal of habituation's importance in understanding annoyance from most other kinds of community noise. The objective of the following theoretical study is to determine whether habituation (and the memory processes implicit in habituation) may be important for understanding and predicting community response to the gunfire and explosions generated from DoD training ranges.

Approach

The approach is to review the literature for evidence of the role of habituation in modifying the annoyance of gunfire from small, medium and large guns. This information will be supplemented by referencing studies of other kinds of noise, such as fast-rise time, short and intense sounds, and sonic booms.

Mode of technology transfer

Most immediately, the knowledge gained will be applied to the analysis of data on the subjective annoyance of individual gun shots and explosions to be collected as part of the ongoing ERDC–CERL, SERDP-funded project, investigate responses to military noise.* In the more distant future, the knowledge of how people respond to repeated blasts – at different intensities and at different inter-stimulus intervals – will be incorporated into recommendations to DoD Range Control Officers for optimizing the use of real-time blast noise monitors, in order to minimize annoyance experienced by citizens living near firing ranges.

* This SERDP project is SI-1546, "An Investigation of Community Attitudes Toward Blast Noise," running from 2008-2013. Point-of-contact is Edward Nykaza, Ecological Processes Branch at ERDC-CERL in Champaign, IL.

2 Literature Review

Definitions and basic concepts

Any discussion of habituation as it relates to auditory stimuli requires an understanding of some basic definitions and concepts.

Habituation

Habituation is a behavioral process which can be demonstrated in animals as simple as the flatworm, planarian (Owren and Scheuneman 1993), and as complex as humans. Studies of habituation generally center around a response which occurs naturally and without previous training. The stimulus for eliciting such a response may be visual, auditory or tactual. Figure 1 shows a mock, idealized habituation curve in which the response decreases exponentially with each repetition of an eliciting stimulus.

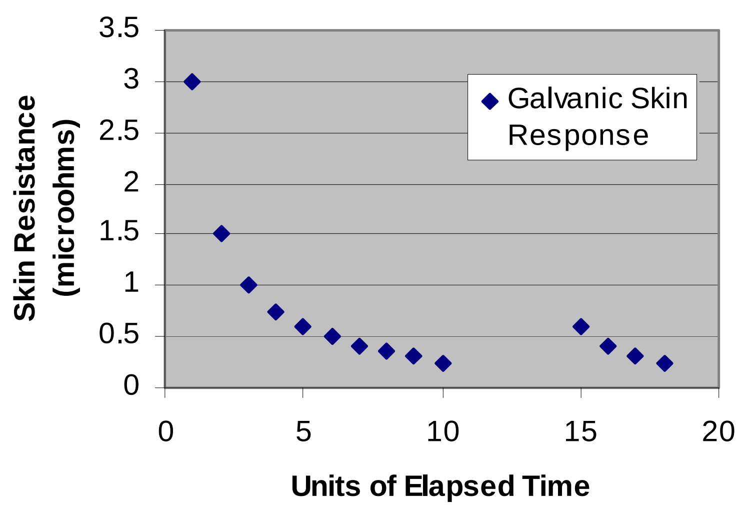

Figure 1. Sample of an idealized habituation curve.

In most studies of habituation, the stimulus occurs at regular intervals, but equal inter-stimulus intervals are not a necessary condition for habituation to occur. Note that when the stimulus is withheld, the response begins to recover over time. Upon reapplying the stimulus, there may be some residual habituation which results in some “savings” in terms of further habituation. In a sense, such “savings” can be viewed as a simple form of memory. Such memories are not, however, generally accessible to human consciousness.

A theory of habituation which is particularly important for understanding human response to sound is the *dual process model* published by Groves and Thompson (Groves and Thompson 1970). From their experience with many different types of habituating responses, these researchers sought to explain why habituation does not always follow the smooth course illustrated in Figure 1. In contrast, Figure 2 presents a graphic illustration of a "non-smooth" course of habituation explainable with their theory.

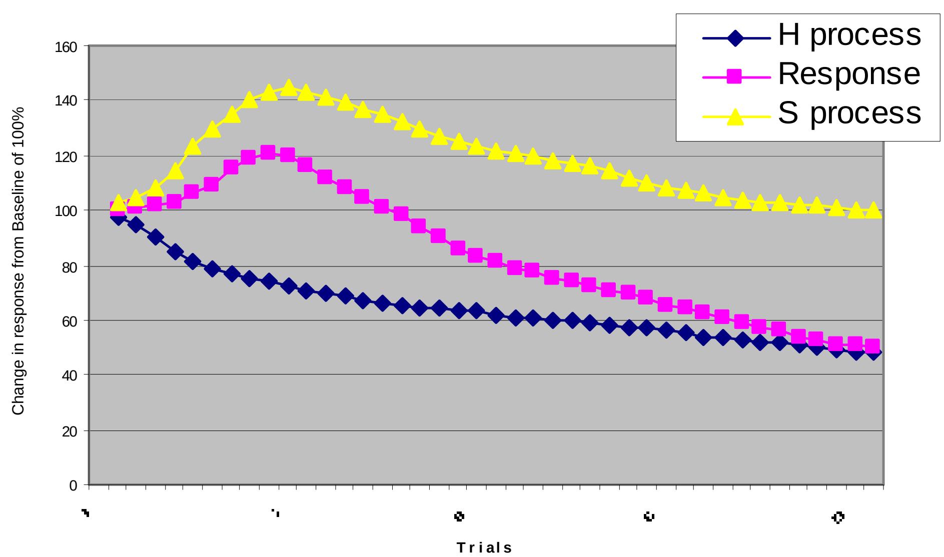

Figure 2. Dual process habituation (adapted from Fig. 1, Groves and Thompson 1970).

In Figure 2, the pink curve, marked "*response*," represents an atypical habituation experiment in which a response actually increases (with the repetition of the stimulus) rather than decreases. The blue curve, marked "*H process*," represents the "habituation process" as it occurs in the pathways of neurons receiving input from sensory neurons and transmitting output to motor neurons. The yellow curve, marked "*S process*," represents the "sensitization process" as it occurs in a set of neurons which are aroused by the stimulus and, in turn, acts on the neurons involved in the habituation.

In describing the interaction between these two processes, Groves and Thompson wrote, “Given that a stimulus elicits a response, whether learned or unlearned, we tentatively distinguish between two inferred systems, the *S-R pathway*, which is the most direct route through the central nervous system from stimulus to response, and *state*, the collection of pathways, systems, and regions that determines the general level of responsiveness or the organism. Habituation is assumed to occur in the S-R pathway and sensitization in the state system” (ibid., 421).

Groves and Thompson found that by employing a family of curves representing the two processes, they were able to match a variety of outcomes from neurophysiological studies of animal reflexes. In addition, their theory proved to be applicable to the acoustic startle reflex in the intact rat. As will be discussed later in this report, the acoustic startle reflex is particularly susceptible to “sensitization” from a psychological *state* commonly called “anxiety.”

One of the proofs of the Groves-Thompson theory may bear on a question which will be addressed later in this report, “Why do groups who are less exposed to blast noise sometimes report the same degree of average annoyance as groups who are more exposed to blast noise?” This particular proof of theory was a rat experiment published by Davis and Wagner (Davis and Wagner 1969), who studied startle responses to 50 msec, 4 kHz tones, presented at a levels up to 120 dB. For humans, such an intense exposure has the potential to be hazardous to hearing, but for the rat, a mammal which is almost as sensitive at 38 kHz as at 8 kHz (Kelly and Masterton 1977), the experience of hearing a short 4 kHz tone is probably comparable to a human hearing a rifle shot.

Prior to beginning the experiment, Davis and Wagner matched four groups of rats on their susceptibility to acoustic startle. On the day of the experiment, each rat was placed into a box designed to measure their movement and allowed to adapt without interference for 30 minutes.

Then, depending on the group to which the rat was assigned, it received at 8-sec. intervals, one of four treatments: (a) 750 exposures to tones at a constant intensity of 120 dB (*120 constant*); (b) 750 exposures to tones beginning at 83 dB and increasing to 118 dB in 2.5 dB increments with each 50 tones (*gradual group*); (c) 750 exposures to a tone at a constant intensity of 100 dB (*100 constant*); and (d) 750 exposures to tones ranging from 83 to 118 dB, presented in a random order with the restriction that the mean intensity in each block of 50 tones was 100 dB (*random group*). For each group, the final test stimulus was a block of 50 120 dB tones, and the question of interest was how well each group was prepared to deal with the most intense acoustic stimulus in the experiment.

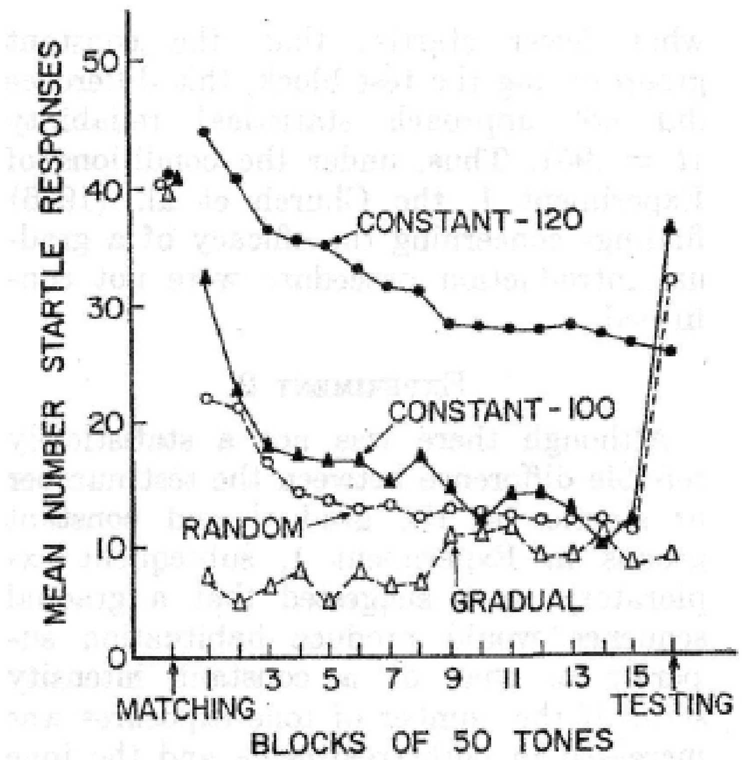

Fig. 2. Mean number of startle responses per 50 tone exposures during the four treatment conditions, and during matching and testing with single blocks of 50 120-db. tones.

Figure 3. Results of a study of acoustic startle (Davis and Wagner 1969).

Figure 3 presents their results. As expected, the highest number of startle responses was measured on the first trial of the group exposed to 50 presentations at 120 dB (45%). However, the second largest number of startle responses was measured during the test trial of the group habituated to 100 dB (36%). In other words, the group habituated to 100 dB was nearly as reactive as rats experiencing 120 dB for the first time, and they also were more reactive than rats who had experienced a random mix of tones ranging between 83 and 118 dB.

When Davis and Wagner's data are converted into the measure commonly used for environmental noise assessments, the equivalent level (Leq), the results are not quite as dramatic, but still impressive. Leq is a measure of total acoustic energy, delivered over a period of time (which, in this case, was 400 sec.).

Prior to the test, the duration of the exposure was 400 sec. For the 120 constant group, $Leq_{(400\ sec)}$ was 136 dB; for the 100 constant group, $Leq_{(400\ sec)}$ was 116 dB; for the gradual group, $Leq_{(400\ sec)}$ was 120 dB. Although an exact calculation can not be made for the random group, the sampling method probably resulted in an Leq slightly higher than the 116 dB of the 100 constant group. In standard environmental noise assessments, an underlying theoretical assumption is that the degree of biological effect (e.g. hearing loss, annoyance) increases with the magnitude of Leq (without regard for the pattern of the presentation of sounds). However, in the Davis and Wagner data, the gradual group (with an $Leq_{(400\ sec)}$ of 120) was much less reactive than the other three groups (with Leqs of 116, slightly higher than 116, and 136).

Sensitization from sound exposure

For the Groves-Thompson theory to be applicable to the understanding of noise annoyance, there must be sensitization as well as habituation. Examples of sensitization from sound exposure are common in anecdotal reports, but rare in the published literature on annoyance. In a later section of this report, an attempt will be made to infer sensitization from five case studies of the annoyance of blast noise. In the meantime, the discussion will be limited to the anecdotal literature.

Previous anecdotal literature available on the Internet received a boost from a book by psychologist Elaine Aron (1996) in which she described the characteristics of a "highly sensitive person," namely one more reactive to all stimuli than are most people. A more rigorous justification for the same concept was published in a journal article (Aron and Aron 1997), but it was the book which empowered people who considered themselves "highly sensitive" to write about their experience.

Some examples of those writings:

- The homepage of a Web site for highly sensitive people, http://highlysensitivepeople.com, listed "can be startled easily" as a characteristic (Hallowes 2009).

- From a patient comment in a blog maintained in 2000 by Dr. John Lester, Department of Neurology, Massachusetts General Hospital (Luz 2000):

  > "I have sound and touch sensitivities that seem to affect the degree of ticking I experience. High pitch noises such as hearing aid whistles, and loud noises such as alarms and TV static seem to 'bring on tics' as well as touching certain kinds of surfaces like unfinished wood, newspapers and chaulk (sic). I find that my tics differ with different sensitivities."

- The following letter[*], received by the U.S. Environmental Protection Agency (USEPA) and forwarded to the U.S. Army Medical Department with names and address deleted, is consistent with a sensitization to the sounds of heavy weapons firing:

  > "We are writing to you after reading the article in the news about the sound wave incident (*sic*) in Eugene, Oregon. We had had similar experiences here off-post of Fort Bragg in Fayetteville. H (*name deleted*) is in the Army and I am a student nurse; we have two children (*names deleted*). We have purchased a home down here and have felt 'vibrations' at various times of the day in this house. These 'sound waves' or whatever they are, rev up and peak and then diminish. All four of us react to them by nervousness, jitternyness (*sic*), and hyperactivity in the youngest. We sense the build-up and cessation simultaneously. This has been going on ever since we moved into this house in November of '76. The acoustics of our house are unreal. At times (we measure by a clap of the hands) sounds just reverberate off the walls. When the house is louder and reflects noise even more the sensation of 'vibrations' seems to build up and gets everyone uptight. We have contacted the Military about this back in November of '77, and all they did was send us through a series of physcological (*sic*) sessions and shrugged their shoulders about any explana-

[*] USACHPPM maintains a file of noise management history for every Army installation. This letter was put into that file by co-author George Luz in 1978, during his tenure with the organization, and retrieved in 2008 for his review by Catherine Stewart, technical monitor for this report.

> tion to us. Is there any information on this that the Environmental Protection Agency can pass on to us? This is very real and until we read that some other people have had similar experiences, we were unsure whether anyone would believe us about this situation...."

A study of habituation (Martindale et al. 1996) was published a year before Aron and Aron published their book and concept of "the highly sensitive person" (Aron and Aron 1997), and it also is consistent with the notion that creative people have more trouble habituating to noise than less creative people. In this case, the noise was 60 dB white noise and the response is one which will be discussed in the next section of this report (i.e., the orienting response), presented through headphones. The low-creative group habituated in only three trials, whereas it took the high-creative group 15 trials to habituate. The medium-creative group exhibited inverted U patterns over trials, a finding explainable with the Groves and Thompson theory of habituation.

Varieties of physiological response to sound

In studies of environmental noise, it is customary to associate the occurrence of a sound with a single psychological process, the perception of loudness. By contrast, in studies of physiological response to sound, consideration is given to up to four responses, all of which are reflected by changes in heart rate (HR). The schema for distinguishing between these four responses was developed by Graham (1979). A schematic for some of the characteristics identified by Graham is provided as Table 1.

Table 1. Characteristics of four physiological responses to sound.

Orienting Response	Defense Response
HR↓ Rapid Habituation Function = Enhance input	HR↑ Slow Habituation Function = Reduce input
Transient Detecting Response	**Defense Response**
HR↓ Slow Habituation Function = Focus on input	HR↑ Slow Habituation Function = Reduce input

Orienting response

The orienting response (OR) appears to have developed to serve the needs of the more complicated nervous system which evolved in mammals. Most of the research into this response is with visual or auditory stimuli, but the OR can be found for tactual and olfactory stimuli as well.

The evidence that the OR is unique to mammals comes from comparisons in which rats and lizards were presented with the same novel stimuli: white noise, amyl acetate, cricket odor, fox odor, and startle pulse (Campbell et al. 1997). Whereas the rats demonstrated a slowing of heart rate (a tell tale sign of the OR) for all five stimuli, the hearts of green iguanas and Sudan plated lizards did not respond to any of those stimuli.

One does not always have to measure heart beats to observe the OR; dog owners observe it when their pets perk up their ears to listen to a distant sound. Russian behaviorist Ivan Pavlov, the first scientist who actually discussed this behavior, named it the "what is it?" reflex (Pavlov 1927, 29). Another Russian physiologist, E.N. Sokolov, studied the OR in more detail and developed a neurophysiological theory in which the habituation of the OR results from the development of a neural model in the cerebral cortex (Sokolov 1963). Evidence for this neural model includes the observation that the OR returns, in response to a *decrease* in the intensity of a habituated sound, as well as to an increase in intensity.

Evidence that habituation to sounds is important for auditory learning has been demonstrated for several species of mammals. For example, exposing adult rats to a 48-hr-long "repetitive non-reinforced sound exposure" can improve their performance in a subsequent two-sound operant learning task (Sakai 2007). Human infants as young as 72 hours demonstrate (a) an OR to speech sounds (head turning), (b) habituation when the sound is presented at the rate of once every 2 sec, and (c) a return of the OR when the speech sound is replaced with another (Brody et al. 1984).

There is also some evidence that the brains of different mammals are "hard-wired" to respond to some sounds with the OR and other sounds with a defense response (DR). Orangutans demonstrate ORs (cardiac deceleration) to white noise, chimpanzee stress calls, chimpanzee alarm calls and chimpanzee threat calls; chimpanzees show comparable ORs to the noise, stress and alarm calls, but cardiac acceleration to the chimpanzee threat call (Berntson and Boysen 1989). The temporal course of this cardiac acceleration is consistent with the growth and decay of sensitization inferred by Groves and Thompson.

Given the essential role of the OR (and habituation of the OR) in allowing people to function in a complex acoustic environment, it is reasonable to expect that people can habituate to a number of sounds at the same time. Evidence for this ability comes from a study of habituation to speech and office noise (Banbury and Berry 1997). The authors examined whether background noise can be habituated to (in the laboratory), by using memory for prose tasks as a measure of performance. They found that background speech can be habituated to after 20 min of exposure, and that meaning and repetition had no effect on the degree of habituation. In a second experiment, they showed that people also can habituate to office noise without speech. In a third experiment, they showed that a 5 min period of quiet was sufficient to partially restore the disruptive effects of the office noise previously habituated to.

The inability to inhibit orienting to low level sounds can be viewed as a handicap, and people who experience this handicap can be expected to be more annoyed by low levels of noise than those who are more able to inhibit their OR to sound. The following are some examples published on the previously-referenced Internet blog maintained by John Lester, M.D. (Luz 2000).

> “All of my life I have been bothered by certain pitched sounds such as humming of an air condition unit, the clicking of the computer keyboard and other things as such. However, when I can control whether the noises happen or not, they don’t bother me. ” (30-year-old female)

> “My son hears EVERYTHING, the crinkle of papers while doing homework is a distraction for him. Sounds that are soft for me are loud for him!!” (a distraught mother)

> “It also drives me crazy when there is more than one noise at a time. I go insane because I try to concentrate on one noise and I can’t since there is another noise begging me to concentrate on it.” (‘Me Too Again’)

> “I am annoyed by mild noises, too. I tune in to noises and can’t concentrate on anything else. It’s especially bad when I try to sleep. If there is a ‘foreign’ noise other than my ceiling fan, I tune in to it, and can’t go to sleep. I have NEVER been able to sleep with the radio or television on. Noise drives me crazy!” (Jenny)

The fact that some people more than others are likely to orient to a low-level sound may explain why there is so much variability in annoyance among people living within hearing distance of small arms ranges. In the previously-referenced study of annoyance around five German small arms ranges, Buchta and his colleagues found a few persons living between 900 and 1,300 meters of a range rating themselves as "strongly" or "very strongly annoyed" (Buchta et al. 1982, figure 5-6, p 92). For a typical person, the sound of gunfire at these distances is not very loud, making the German findings surprising at these distances, since from 1974-2004, the Army Environmental Hygiene Agency (Army Center for Health Promotion and Preventive Medicine) received no data on noise complaints from people living at similar distances from U.S. Army small arms ranges. *

* This observation by co-author Luz covers the period he served as Program Manager for the Army Medical Department's Environmental Noise Program, where it was standard practice for installations to consult if receiving noise complaints. In addition, at Fort Dix, NJ, there are homes located within 150 m of firing lines that are used for training with the M-16. Residents have not complained or asked the Army for noise abatement. Details on this exposure can be found in a report (limited to U.S. government agencies) available from the U.S. Army Center for Health Promotion and Preventive Medicine: "Environmental Noise Assessment No. 52-34-0464-87, Monitoring of the Zone III," Fort Dix, NJ, 18-25 November 1986.

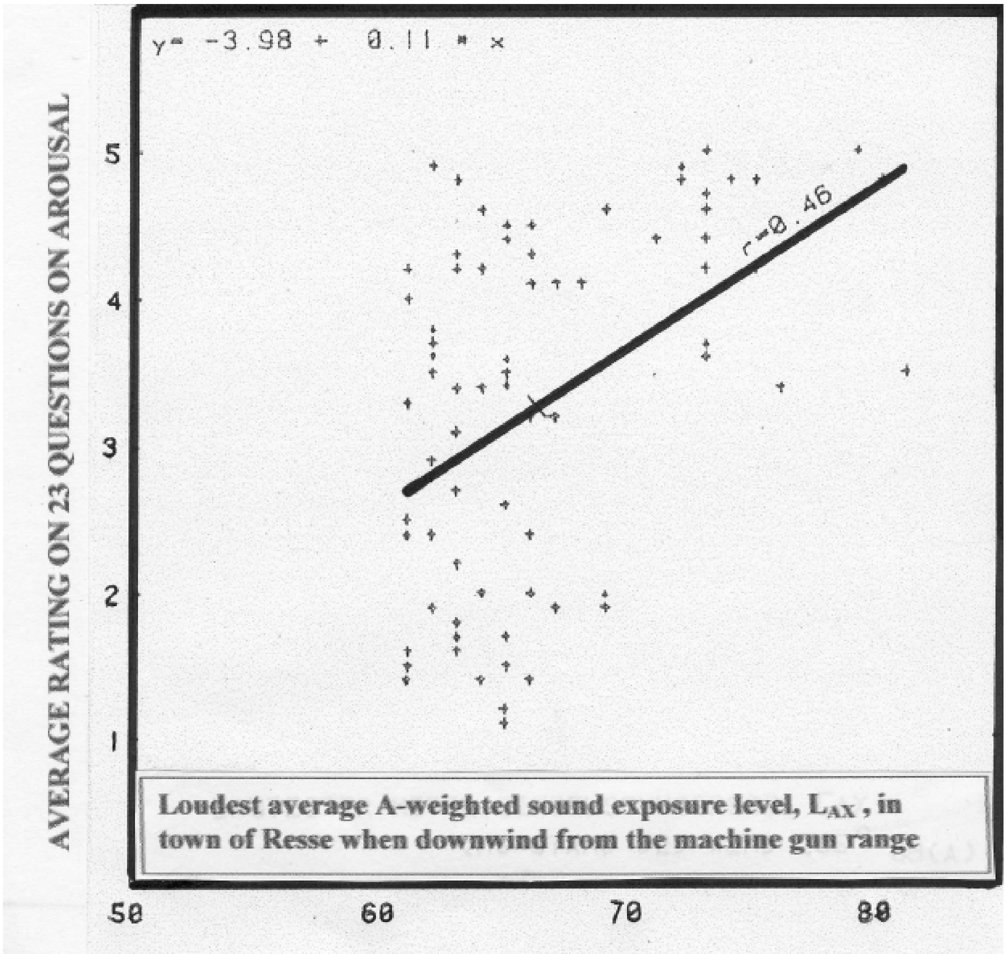

Figure 4. Relationship between the worst case (downwind) level of machine gun fire experienced by citizens of Resse and their subjective annoyance reports concerning small arms fire (Buchta et. al. 1982).

The most compelling example of the variability between individuals came from interviewees in the town of Resse, Germany (Figure 4). The acoustic stimulus for Resse was the machine gun which, because the separate gun shots are heard in rapid succession, is distinctly recognizable from other types of gunfire. Based on a fairly careful noise measurement study, the researchers were able to project the level of the machine gun at various distances from the range under “worst case” conditions (i.e., Resse downwind of range). Among those interviewees at residences where the worst-case levels of single shots exceeded an A-weighted SEL of 70 dB, everyone was annoyed to some degree. Among those interviewees at residences where the worst-case levels were below 70 dB, there was considerable variation, with some interviewees being very annoyed, and some being not at all annoyed. Although it is reasonable to expect, based on studies of the masking of gunfire (Vos 1998), that some of the interviewees reporting low annoyance were experiencing mitigation because of background noise, such masking would not appear to be a complete explanation.

Transient detecting response

Of the four responses, the transient detecting response (TDR) is the least defined in the research literature. One pair of experts has written that the TDR "results from the active processing of the stimulus by a high pass filter, which is sensitive to stimulus change but not steady-state stimulus characteristics" (Cook and Turpin 1997). In this study, the authors hypothesized that the TDR is "associated with behavioral orientation (eye and head movements) particularly in neonates," and they indicated that the TDR is "not necessarily associated with stimulus identification or discrimination."

However, this interpretation contradicts the findings with 72-hour-old neonates (as discussed above) in which head turning to speech sounds demonstrates habituation specifically keyed to the auditory stimulus. Another expert notes that the TDR occurs at low-stimulus intensities, and is "associated with a small, but persistent, heart rate deceleration," as an indicator that a stimulus "has been detected but not necessarily recognized," and "may serve to gate or attenuate subsequent high intensity stimulation" (Őhman 1997). In short, the TDR appears to act in the same manner as an "interrupt" in a computer's operating system, by temporarily focusing the brain on input received from one of the sensory systems.

The importance of the TDR to an understanding of annoyance is unknown. One hypothesis is that overloading the TDR with rapidly-repeated impulsive sounds, such as from an old-fashioned teletype machine, could be particularly annoying to some noise-sensitive people. An experiment which would be consistent with this hypothesis is a study of the annoyance of 4.8 sec segments of white noise reported by Kuwano et al. (2005). Table 2 lists the nine stimulus conditions used in the experiment.

Table 2. Characteristics of the nine sounds used by Kuwano, Fastl and Namba (2005).

No.	I: Intermittent S: Steady-state	No. of component sounds	off-time (ms)	LAE (db)
1	I	5	900	66
2	I	10	420	63
3	I	20	180	66
4	I	40	30	69
5	I	60	20	71
6	I	80	0	72
7	S	—	—	60
8	S	—	—	66
9	S		—	72

The maximum A-weighted level for Stimulus 9 was 70 dB with a Sound Exposure Level (LAE) of 72 dB. At the other extreme, Stimulus 1 had the same maximum level, but its LAE had been reduced to 60 dB by four 900 msec gaps of silence. Between these gaps of silence were five bursts of white noise with 30 msec rise and fall times.

Said differently, Stimulus 1 was five distinct bursts of noise, presented at the rate of one per second. For Stimuli 2 to 6, the number of intermittent sounds was increased, and the gaps of silence were decreased in proportion. The participants were required to judge the loudness of each sound by assigning a positive number which they felt reflected the loudness.

The results are shown in Figure 5. At LAE below 70 dB, intermittent sounds were judged to be louder than the steady state sounds even if LAE values were equal. The difference became larger as the interval between component sounds became longer. In subsequent experiments, these researchers showed that the intermittent sounds were also more annoying and unpleasant than the steady-state sounds.

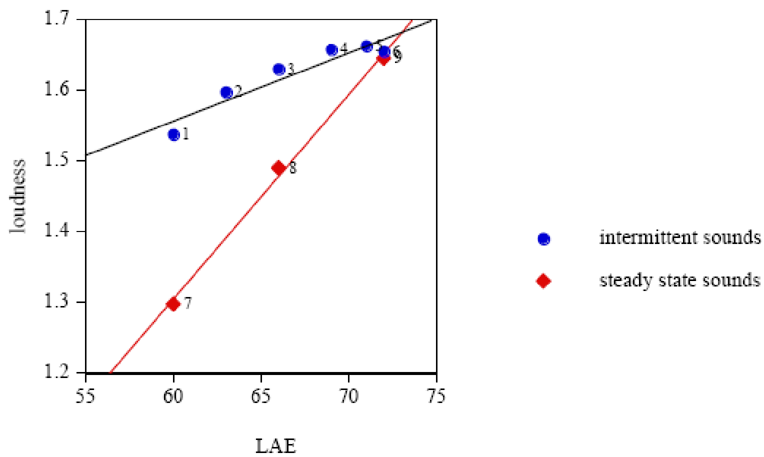

Figure 5. Results of comparison of steady state and intermittent sounds (Kuwano, Fastl, and Namba 2005).

The rate of intermittency at which the Kuwano team found the largest disparity (1 per sec), is close to the rate of intermittency used in laboratory experiments, demonstrating the need for a "level-dependent penalty" for small arms fire (e.g., one every 1.2 sec.), (Vos and Smoorenburg 1985).

The level-dependent penalty was first observed in a series of round-robin tests conducted in several participating countries. Summarizing this work, Rice (1983) wrote, "Impulse noises heard in isolation require a level dependent correction which varies 0 to 10 dB over the range of 70 to 35 dB L_{Aeq}." Six years later, Rice reiterated the importance of the level-dependent penalty by stating, "In those cases where an impulsiveness penalty is justified, it should be 10 dB at an outdoor measured sound level of 50 dBA L_{Aeq}, decreasing by 1 dB for every 3 dB increase in outdoor measured sound level up to 80 dBA L_{Aeq}." (Rice 1989).

Defense response

Loud sounds lead to defense responses (DR) in which there is cardiac acceleration. A precise physiological definition of "loud" is beyond the current state of knowledge, but Dimberg (1990) has been able to bracket that value within a 20 dB range. Working with 1 kHz tones having a rise-time of 40 msec to avoid eliciting the startle response, Dimberg looked at the response of facial muscles, heart rate (HR), and skin conductance response (SCR) in reaction to 75 and 95 dB tones. He concluded, "The response to the 75-dB tone displayed characteristics typical of an orienting response with a distinct initial HR deceleration and fast habituating SCRs with a relatively short half recovery time. The response to the 95-dB tone, on the other hand, displayed aspects of a defense reaction indicated by a tendency to HR-acceleration and larger, slowly habituating SCRs with retarded recovery rate." Further evidence that the 95 dB tone was aversive came from subjective ratings stating it to be unpleasant and activity in the corrugator muscles of the face. (The corrugator muscles are responsible for the human "frown.")

Habituation of the DR to loud sound results in a downregulation of arousal. If the loud sound is predictable, the DR may even appear shortly before the sound occurs. An example of such anticipation was found in a study of individual differences in cardiovascular responses to intermittent noise in females (Petiot et al. 1988). Subjects were exposed to 105 dBA noise in three sessions over the course of three weeks. Each session was 35 min long and began with 5 min exposure to 40 dBA pink noise*, followed by 5 min exposure to 105 dBA pink noise. This sequence was repeated two more times within the session for a total of three transients per session.

From the second or third transient onward, the HR increase was anticipated by an increase during the last minute *before* the onset of the loud noise. Examination of individual data showed that this conditioned increase of HR took place earlier in some subjects than in others. It was shown by all subjects from the second session onward.

The degree of habituation of the DR which can be achieved will depend on the amount of autonomic arousal already present. Working with an even louder sound (one sec of a ship's bell at 115 dB), Epstein and Fenz (1970) demonstrated that a subject's self report about their arousal predicted the amount of downregulation of the galvanic skin response (GSR) that they could achieve. An example of a question on the self-report of arousal is, "In the absence of physical action my heart beats wildly," with possible answers ranging from 1 (never) to 5 (all the time).

Individual differences in the ability to habituate to the DR are reflected by variability of the transition zone between OR and DR as the intensity of sounds is increased. In a theoretical distinction introduced by Petrie

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* "Pink noise" is different from "white noise" by an adjustment to the total acoustic energy in each successive octave band. The adjustment ensures that the total acoustic energy in each octave band is equal. In contrast, "white noise" has equal energy at each frequency, and because the number of frequencies doubles with each successive octave band, the energy per octave band also doubles with "white noise." Subjectively, "pink noise" sounds like a lower frequency sound than "white noise."

(1967), people can be divided into “augmenters”, “reducers” and an in-between group, “moderates.” The reducer tends to decrease what is perceived, the augmenter to increase it, and the moderate to do neither.

An example of these differences in downregulation can be found in a study of the physiological responses of augmenters and reducers exposed to 500 msec bursts of noise when delivered at intensities ranging between 65 and 105 dBA (Schwerdtfeger and Baltissen 2002). The rise and fall time of these stimuli were 50 msec, a duration which is unlikely to elicit startle responses.

Figure 4 of Schwerdtfeger and Baltissen’s study shows the change in pulse rate during the first 4 sec following presentation of a stimulus. Whereas both augmenters and reducers demonstrated the deceleration of the OR in response to the 65 dBA sound, the amount of deceleration was greater in the augmenters than the reducers. Moreover, at 95 and 105 dBA, the augmenters showed a more immediate transition to the acceleration of the DR than did the reducers.

Finally, the distinction between OR and DR is important for understanding the annoyance of heavy weapons, compared to small arms noise. Whereas people reporting annoyance from small arms ranges are rarely, if ever, close enough to experience levels sufficient to elicit a DR, people reporting annoyance from heavy weapons blasts do, on occasion, experience such intense levels.

An example is found in the study of Germans living near tank gunnery ranges (Buchta et al 1986). In Figure 5-23 of that study, the Buchta team documented the increase in the percentage of people who report significant arousal as the average blast level increased (Ibid., fig. 5-23, p 116). The three data measures were “erschreckten” (alarmed, frightened, startled), “verängstigten” (intimidated), and “nacts geweckten” (awakened at night), presented in Table 6.

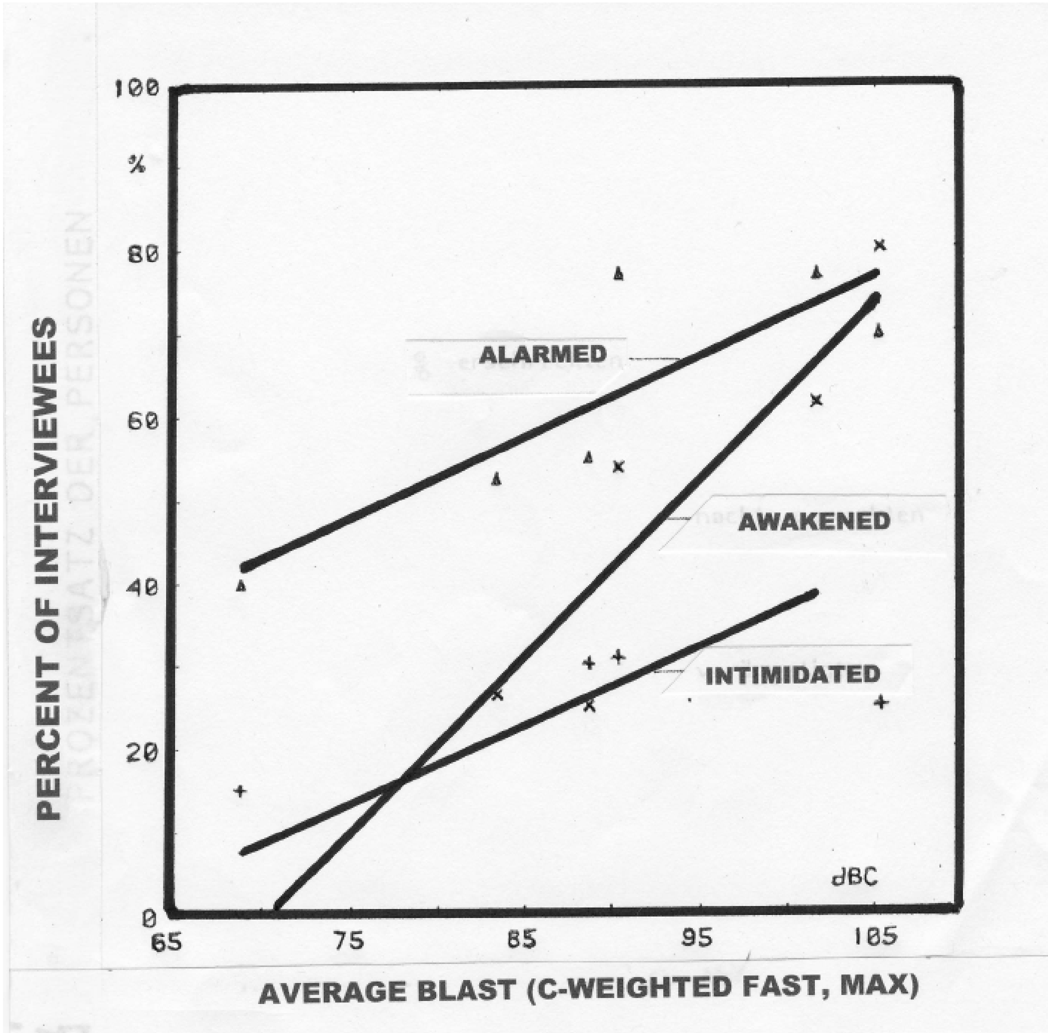


Figure 6. Arousal from blast noise reported by German citizens living in the vicinity of troop training areas (Buchta et al. 1986).

Startle response

The acoustic startle response (SR) is the only response for which there is evidence that sensitization (as envisioned in the Groves-Thompson theory), has an inherited (genetic) component; a long-term, learned component; and a short-term, situational component.

In humans, the preferred method of studying acoustic startle is measuring the blink of the eye. A long-standing requirement for studies of acoustic startle has been that the sound be sudden and intense. According to Graham, “there must be a sufficiently large change in stimulation occurring within approximately 10 msec” (Graham 1980).

As for the definition of “intense,” Berg determined the threshold of startle in humans to be 85 dBA for a 50 msec burst of noise (Graham 1980). More recent work by Blumenthal and Goode has demonstrated startle down to 60 dBA (Blumenthal and Goode 1991). Because the SR can be elicited over such a large dynamic range and because off-the-shelf equipment for measuring the eyeblink is available from commercial vendors, the acoustic SR is now widely-used to study individual differences (e.g., extraverts vs. introverts) and emotional processes. Much of this work uses a paradigm known as “pre-pulse inhibition” in which a less intense (e.g., 50 dBA) pulse precedes the SR-eliciting sound by a few milliseconds. It is thought that the pre-pulse sound elicits the TDR, which in turn, inhibits further auditory input until the nervous system can process the incoming information.

The method for inferring the effect of emotion on the SR is to show the subject positive, neutral, and negative images. The images are frequently drawn from The International Affective Picture System (Lang, Bradley, and Cuthbert 2005). In the first study to demonstrate the effect of emotion on acoustic SR, the negative slides included mutilated bodies or faces, a spider, a coiled snake, a gun, and a man receiving an injection. Neutral slides included common household objects. Positive slides included opposite sex nudes, smiling children, a rabbit, and appetizing food. Magnitude of the SR was lowest during showing of the positive slides, and highest during showing of the negative slides (Vrana et al. 1998).

A gene variant which modulates the effect of negative images on the startle response is the Met158 variant of the gene known as COMT (catechol-O-methyltransferase encoding). The Met158 variant is only found in some humans; all other primates have the original form of COMT, known as Val158. The difference involves the substitution of a single amino acid, methionine, for valine at the 158th position on a long protein responsible for breaking down dopamine, a neurotransmitter, in parts of the brain important for the regulation of emotion.

The fact that mankind’s genetically nearest relative, the chimpanzee, does not have the Met158 variant, leads to speculation that the heightened wariness associated with this gene gave certain human ancestors a competitive survival advantage. Presumably, “It was an advantage to be more anxious in a dangerous environment”(Montag 2008). Currently, about half of the world’s human population carries one copy of each variant, the other half carries either two Val copies (about 25%) or two Met copies (about 25%).

To determine the influence of these variants on the acoustic SR, a German-based team studied 96 females of German ethnic origin who were drawn so as to be representative of the three combinations (Montag et al. 2008). They showed that subjects with two Met158 copies exhibited a markedly increased SR during presentation of the negative stimuli, when compared with subjects with the Val158 variant.

In addition to the inherited effect on the acoustic SR, there is a body of scientific literature on how individual experience, particularly traumatic events, can modify the SR response to sound. Much of this literature has been published by a team from the Yale University Medical School. Morgan's study compared the SR of Vietnam War veterans with post-traumatic stress disorder (PTSD) to the SR of control subjects (Morgan et al. 1995). The sound used to elicit the SR was a 106 dB burst of white noise. Responses to this sound were measured before (i.e. baseline) and after conditioning to associate this sound with a mild (2 mA, 5 msec) shock. The PTSD group showed significantly greater startle responses during both baseline and shock anticipation than did the control group. Similar results were found with veterans who had symptoms of PTSD from the first Gulf War (Grillon and Morgan 1999). For the Vietnam War veterans with PTSD, the effect was heightened further by testing under dark conditions (Grillon et al. 1998).

The effect of PTSD on the acoustic SR is not limited to combat veterans. There also are startle reflex abnormalities in women with sexual-assault related PTSD (Morgan et al. 1997). In addition to serving as a means of confirming PTSD, the acoustic SR has potential as an indicator of when treatment for PTSD has been successful. Griffin and Resick examined 63 female rape and physical assault survivors with PTSD, before and after cognitive-behavioral therapy (Griffin and Resick 2004). They measured acoustic startle response, heart rate and skin conductance in response to auditory startle stimuli. Among those patients whose treatment had been reported as successful, there was a significant decrease in acoustic SR.

The importance of startle as a variable for understanding subjective annoyance to noise has been studied for sonic booms and simulated gun blasts. A summary of four studies of startle to sonic boom was published by Thackray et al. (1975). As can be seen in Table 3 below, the threshold for arm or hand movements is higher than the threshold for eye blink. In addition, the heart beat data showed that outdoor sonic boom levels up to 128 dB peak sound pressure level (SPL) resulted in an OR, while levels in excess of 135 dB peak SPL resulted in a DR.

Table 3. Startle responses to sonic booms (Thackray et al. 1975).

Linear peak SPL	Eye Blink Incidence	Arm/hand Movements	Heart Rate Change	Other Subjective Observations
118	10%	none	Deceleration	Repeated exposure likely to be annoying
123-128	40-80%	10-20%	Deceleration	Repeated exposure likely to be mildly to moderately annoying
132-134	30-50%	25%	No data	No data
136-138	90%	55-70%	Acceleration	Repeated exposure likely to be moderately annoying
139-143.8	No data	55-70%	No data	No data
144-150	No data	83-100%	No data	No data

The threshold for DR shown in Table 3 is about the same as a threshold for sonic boom annoyance reported by Rylander et al.(1972). In this case, the soldiers were from an engineering regiment who had established a field base and were constructing roads inside a supersonic flight corridor, with up to 19 booms per day. Based on interviews with 165 soldiers, the Rylander team concluded that the threshold of annoyance was 1 mbar (134 dB peak SPL).

Evidence that the startle response, per se, has a role in the annoyance of sonic booms comes from the previously referenced NASA-Langley *in situ* study of sonic boom annoyance (McCurdy et al. 2004). As previously noted, test subjects went about their daily activities while exposed to between 4 and 63 simulated sonic booms each day. At the end of the day, subjects were asked four questions, one of which was, “Were you startled by any of the sonic booms today (yes or no)?” The authors concluded, “Annoyance is greater when the test subject is ‘startled’ and the magnitude of the increase in annoyance increases as sonic boom exposure increases.”

Working with eye blink startle and electrocardiogram changes in response to simulated large and small firearm blasts, Vos found an orienting response followed by a defense response at 64 dBA (impulse). The 80 dB impulses produced by the small firearm yielded a defensive reaction, while those produced by the large firearm yielded a significant startle reaction. When subjects were involved in a tracking task, however, there was a complete absence of both defensive and startle reactions (Vos 1999).

3 Memory Processes in Studies of Blast Noise Annoyance

Both habituation and annoyance involve memory of repeated sounds. In the first case, the nervous system cannot stop responding to a sound without developing some sort of memory for key feature(s) of that sound. In the second case, interviewees cannot report their annoyance without tapping into a memory of their brain's cumulative experience of the acoustic environment.

For a person living next to a busy highway, the demands for memory are minimal, since the offending noise is always present. Nevertheless, a standard practice recommended by the International Organization for Standards (ISO) is to ask interviewees to report annoyance over the past year, not the day of the interview (ISO 2003). Based on past social surveys of people exposed to sonic booms, heavy weapons, and explosions, it appears that the memory for these events has three features: (1) A relatively high threshold for registering the number of events, (2) a long duration, and (3) a tendency to primarily remember the most intense events.

High threshold for registration

The only experiment in which residents were asked to report the number of booms which they had heard was a sonic boom study conducted in Burgsvik, Sweden, during the early 1970's (Rylander et al. 1974). Because the population of Burgsvik was relatively small, the investigators were able to interview one adult representative from every household in town.

Representatives were divided at random into five groups of 40 interviewees, and one group was interviewed over the first five of the six days of exposure. On the last day, all the persons who had been present during the entire exposure (146 persons) were given a final interview. Table 4 gives the level (pascals) and number of sonic booms on each exposure day, and Table 5 gives the average number of booms remembered by the interviewees.

Table 4. Number and level (in pascals) of booms experienced by citizens of Burgsvik, Sweden, on six different days (Rylander et al. 1974).

Successive Days of Exposure to Sonic Boom					
Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
10	45	13	20	35	40
		185		13	20
		10		75	18
		25		95	12
		3			30
					30

Table 5. Number of booms remembered by citizens of Burgsvik, Sweden (Rylander et al. 1974).

Actual Number of Booms	Average Number of Booms Remembered
1	1.3
4	1.7
5	1.5
6	3.7

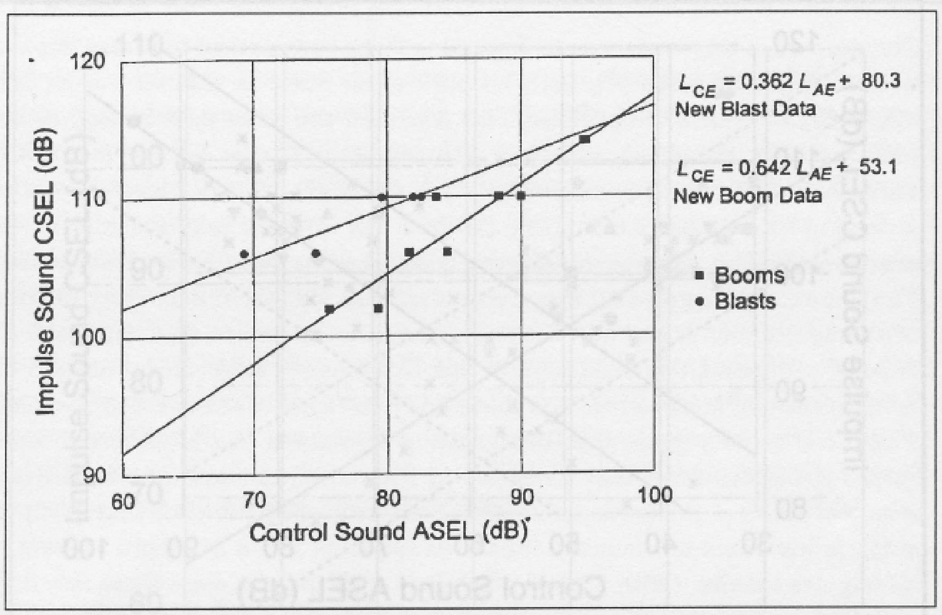
As noted by the study's authors, the number of booms "heard" increased when the number of actual exposures reached six. A possible reason for this rather fuzzy memory of the daily number of events is that only 11% of the booms were above the threshold for the DR as discussed above. For sonic booms, that threshold appeared to be at some level above 128 dB, but below 136 dB linear peak.

Further evidence that the intensity range from 128 dB to 136 dB linear peak is critical for understanding the annoyance of high-intensity impulsive noise comes from a comparison of the annoyance of explosive and sonic boom noise (Schomer, Sias, and Maglieri 1998). These researchers from USA-CERL conducted the only *in situ* study in which response to actual sonic booms was compared with response to actual explosions.

In the USA-CERL study the authors stated, "the outdoor flat-weighted peak sound pressure levels of booms measured at the face of a building generally ranged from about 120 to 135 db." (ibid., 12)

The study was performed during August 1995 at the Naval Air Station (NAS) at Fallon, NV. Paid volunteers were tested, while inside three different structures. One was an adobe brick house with a flat timber beam roof damped by a layer of gravel. The second was a small, wood frame building, measuring 3 m x 6 m. The third was a mobile trailer divided into two 3.5 m x 8.5 m rooms. (Photos of the buildings can be found in the referenced technical report.)

Each of the test rooms was furnished like a normal living room, with closed windows and an acoustically-friendly air conditioner [40 dBA background]. Care was taken to ensure the noises, a sonic boom from a U.S. Navy F-5 fighter aircraft and detonation noise from military-grade C-4 plastic explosives, both arrived at each building from the same direction. Since the logistics of a direct comparison between a sonic boom and a ground detonation would border on the impossible, the researchers compared each source with a control sound (a time-shaped, 0.5-sec burst of 200 to 1500 Hz band-limited white noise presented through loudspeakers in each room). A procedure known as paired-comparisons was used to find that level of the control sound (measured in A-weighted SEL) which was reported as equally as annoying as the real-life explosive events (measured in C-weighted SEL).



Only the recent NAS Fallon data are shown. Regression lines are shown for each data set separately.

Figure 7. Comparison of the increase in annoyance judgments for sonic booms with military explosives in which both events were experienced “live” in typical residential structures (Schomer et al. 1998).

Figure 7 is a copy of Figure 8 as presented in the 1998 USA-CERL study. It shows that annoyance of sonic booms increased at a faster rate over the range of 120 to 135 dB peak SPL, than did the annoyance of explosions. Said differently, the transition zone between a non-annoying and very annoying explosion of C-4 was broader than was the transition zone for a sonic boom. Whether the decibel range of the transition zone would have any effect on the accuracy of the daily count of events cannot be determined from the USA-CERL study, since the subjects knew that they would be hearing an equal number of sonic booms and explosions in each experimental session. At the same time, it is reasonable to expect that a broader transition zone would be associated with a lower threshold of registering events.

Although there are no studies of heavy weapons noise in which interviewees were asked to report the number of events per day, there are two studies of heavy weapons noise which suggest that people have a separate memory for level and for number.

The first is a study of artillery noise annoyance conducted at Australia's Holsworthy Range (Bullen, Hede, and Job 1991). In this study, the researchers concluded that the daily number of blast events may add to the predictive power of equal-energy units as a predictor of community annoyance.

A weakness in this Australian study is the methodology for making acoustic predictions. All the authors were social scientists, and they used statistical procedures developed for social scientists to produce equations that predict the propagation of blast noise.* In this regard, the Holsworthy Range study is the weakest of the studies discussed here. At the same time, the fact that the daily number of blast events showed up as important in spite of the fuzzy methodology for acoustic predictions, suggests that this must be an important variable in the annoyance of heavy weapons.

A much better acoustical model was used in the second study, which was based on a postal questionnaire returned by 1,483 randomly selected Swedish residents living in 20 areas around eight military ranges that con-

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* Standard practice in studies of community noise annoyance is to use a computer model of the physical acoustics of sound production and sound propagation to generate a noise exposure map for the community. For example, in studies of annoyance of Army weapons noise at Ft. Bragg, conducted by USA-CERL, the exposure was estimated using the BNOISE model (Schomer 1982).

ducted heavy weapons training (Rylander and Lundquist 1996). Among the analyses performed was a breakdown of annoyance from persons exposed to blast noise levels with SEL values between 90 and 95 dB(C) vs. people exposed to SEL values in excess of 95 dB(C).

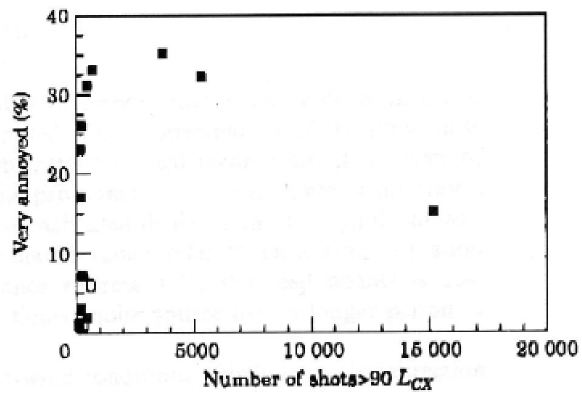

Figure 8. Relation between extent of annoyance and number of shots exceeding a C-weighted SEL of 90 dB for areas where the maximum SEL was up to 95 dB, and above 95 dB (Rylander and Lundquist 1996).

As shown in Figure 8, for those in areas where the worst case levels were below an SEL of 95 dB(C), the growth of the percentage of "highly annoyed" people as a function of annual number of shots was mild (not exceeding 8% highly annoyed). For those living in areas where the worst-case level was above an SEL of 95 dB(C), the annoyance jumped dramatically when the annual number of shots exceeded 200. Presumably, the linear peak level corresponding to an SEL of 90 dB(C) is 115 dB linear peak, the same threshold identified by Pater as the threshold of complaint for weapons noise (Pater 1976).

Long-duration memory

Evidence that memory for the annoyance of heavy weapons noise stretches back farther in time than for other types of intrusive noise comes from an analysis of social survey data collected in the early 1980s from the vicinities of Fort Bragg, North Carolina, and Fort Lewis, Washington (Schomer 1983).

In these surveys, interviewees had an opportunity to report their annoyance for helicopters, aircraft, street traffic, and neighborhood noise from children and pets, as well as to the subject of interest, artillery. As part of the survey, respondents were asked whether or not they were generally home during the day, evening, or night, both for weekdays and weekends.

Respondents home during a given time period were asked if they were bothered by any of the five sources and, if so, how often were they bothered. The interviewee could check off a response of: every day, several times a week, several times a month, once every few months, or less than a few months.

For airplanes, helicopters, street traffic, and children or pets, the longest period checked was "several per month." Only for artillery were there interviewees basing their annoyance on remembering exposures "once every few months." Interviewees who chose this category were particularly annoyed by night fire. For those remembering their annoyance at night, 43% were "highly annoyed." High annoyance dropped to 26% among interviewees remembering evening annoyance and to 9% for those remembering daytime annoyance.

Further evidence for a long duration memory comes from a study of annoyance around a demolition ground at a U.S. Navy Ammunition Depot in Crane, IN (Green 1973). Of the 966 residents surveyed, some lived as close as 5 miles and some farther than 20 miles from the detonation of explosions, with explosive weights up to 500 lbs. When asked when they had last heard the demolitions, 84% reported that it had been longer than three years. In spite of this long passage of time, six percent still reported being "bothered" by the explosions.

Remembering the most intense events

Evidence that people tend to remember the most intense impulsive noise events comes from the two surveys of heavy weapons noise referenced in the introduction of this report, and from a survey of noise annoyance around quarries conducted in the United States.

In the first of the German studies, the funding organization (the German Ministry of Finance) was interested in whether communities were more annoyed by military noise around the two training areas used by U.S. and NATO forces (Hohenfels and Grafehwöhr) than around the exclusively German training areas (Bergen, Senne, and Munster). The researchers intended to use a cumulative, Leq-based (Equivalent Continuous Noise Level) measure as the acoustical measure, but their plans were derailed by the security restrictions imposed by the 7^{th} Army Training Command (7ATC) of the U.S. Army in Europe (USAREUR). The 7ATC refused to provide data on the number of each type of munitions fired by U.S. Forces over the course of a training year, and without both level and number, calculation of Leq is not possible.*

The German researchers got around this restriction by concentrating on the sound which the interviewees reported to be most disturbing – blasts from the main guns of 105 mm and 120 mm tanks. At all but one of the five installations (i.e., Senne, where low-level military flights were marginally most annoying), 105 mm and 120 mm main gun blasts were the dominant source of annoyance.

The researchers also conducted extensive field measurements to develop equations for predicting tank gun blast levels. With these equations, the Buchta research team was able to define the correlation between the energy-averaged tank gun blast and the psychological effect. For overall (global) annoyance, the correlation was r = 0.66 (Buchta and P. Rohland 1986, 83).

By the start of the second study, the German government and USAREUR had established that the Soviet Union could not deduce the annual number of rounds of each type of munitions fired at Grafenwöhr if the results were plotted only as a map on annual noise exposure. Consequently, the Buchta team conducted an even more extensive field measurement study than in their first study.

From these noise measurement data, they developed a German version of the USA-CERL's BNOISE computer model†. The resulting noise contour map for Grafenwöhr Training Area was based not only on 105 mm and 120 mm tank guns but also on howitzers (155 mm and 203 mm), mortars (107 mm and 120 mm), chain guns (20 mm and 25 mm), rockets (35 mm , 66 mm, and 152 mm), military explosives greater than and less than 2 kg explosive weight, and hand grenades.

When the team looked at the correlation between overall annoyance and the average level of a single blast, the size of the correlation was almost half of what had been observed in the earlier study: r = 0.35 (Buchta 1988,

* Reference to the denial of operational data to the German Ministry of Finance is not to be found in the written record. Author George Luz knows of the refusal to release numbers of rounds because he was acting as a consultant to the Under Secretary of the Army and USAREUR at that time.

† The Construction Engineering Research Laboratory's (CERL's) blast noise prediction computer program (BNOISE) is used to produce noise contours for Army installations.

p 116). By shifting the physical stimulus from the high end of the statistical distribution of all blasts experienced by the interviewees down to the true average of all the blasts experienced, the researchers had degraded the correlation between the physical and the psychological.

A similar degradation of the psychophysical relationship was found in the multiple correlation statistics for the respective situations. In the 1986 study, the C-weighted fast level of the average tank blast explained 41% of the variance followed by attitude toward the installation with 18% of the variance and the potential to habituate with 3% (Buchta et al. 1986, p 129). In the 1988 study, the potential for habituation accounted for the most variance (27%) whereas the physical stimulus (the daytime C-weighted Leq) accounted for only 9% of the variance. In fact, the 1988 multiple correlation showed the physical stimulus accounting for less variance than two other attitudes: self-reported health status (9%) and value placed on the neighborhood (5%) (ibid., 121).

Thus, by concentrating on the average event rather than the worst case event, Buchta's team went from a study in which acoustic variables explained most of the variance in annoyance to a study in which psychological variables explained most of the variance in annoyance.

The importance of the high end of the statistical distribution for predicting the cumulative annoyance of impulsive events is reinforced by a study conducted around two surface mines and a quarry (Fidell et al. 1983). This study is unusual among blast annoyance studies in that the physical stimuli were estimated levels of vibration from air and ground-borne pressure waves.

When the research team plotted annoyance judgments against the cumulative annual vibration level, the data from the three blasting operations fell along three different curves. Only after introducing a non-standard adjustment in which the top 14% of the annual statistical distributions of events for each location were weighted (by cubing their energy), were the researchers able to align the annoyance judgments from the three sites.

The argument could be made that the results from this surface mining study are irrelevant, since the acoustic spectra of contained explosions contains so much infrasound as to be usually inaudible.

On the other hand, vibration is ubiquitous in studies of the annoyance of military heavy weapons. Vibration was mentioned in 54% of blast complaints received by the Army over a one-year period (Luz et al., 1983), and in 18% to 26% of the complaints received by Japanese authorities responsible for Japanese artillery training areas (Koyasu et al. 1999). In the Australian study of the Holsworthy Firing Range, vibration was considered to be such an important variable that it was incorporated into the equation for predicting general annoyance to artillery training. Laboratory studies conducted at USA-CERL have shown that the perception of vibration (in the form of window rattle) amplified the annoyance of medium intensity blasts (Schomer and Averbuch 1989).

4 Analysis of Case Studies

A hallmark of the dual process theory of habituation are studies with anomalous results which are explainable by reference to the second process, sensitization. Five case studies in the annoyance literature can be interpreted in terms of the dual process theory.

Case Study 1: All blasts detectable.

In 1963, the Royal Aircraft Establishment in Farnbourough, England, studied the response of a community of 280 people to 0.2 kg, .9 kg, and 3.4 kg detonations of plastic explosive, suspended by balloon at a height of 137 m above the village (Webb and Warren 1962).

With most of the community located between 662 m and 844 m from the explosions, the range of intensities across the community was within 6 dB. The level of the 0.9 kg charge ranged from 135 dB (2.3 psf) to 141 dB linear peak (4.9 psf). At these levels, everyone in the village could be expected to hear every detonation.

The study, which was intended to further the understanding of community response to sonic booms, was called Project Yellowhammer. The exposure, which took place primarily on Monday and Tuesday of each week, was spread over 14 consecutive weeks. For the first five weeks, the community was subjected to a standard series of bangs, nominally 24 in number, and spread randomly throughout the day between 0930 and 1530.

During the sixth week, the number of detonations was reduced to eight, and in the seventh week, the time was shifted to the morning (0700 – 1200) with a return to the standard time and exposure during the eighth and ninth weeks. For purposes of analysis, these first nine weeks are considered to be the habituation exposure.

On Thursday of each week, a sample of the community was asked the following question: “Taken as a whole did the bangs you have heard this week BOTHER or ANNOY you in any way?” Interviewees had a choice of “very much”, “moderately,” “only a little” and “not at all.” In spite of the intensity of these explosions, fully half of the interviewees during the first week of exposure stated that they were “not at all” annoyed, and the proportion of "not at all" annoyed continued to increase with each week of exposure until, after the ninth week, it included over 70% of the interviewees .

This "habituation curve" is shown in Figure 9, where the plotted percentages represent interviewees who were "only a little," "moderately" or "very much" bothered or annoyed. The "habituation curve" for the interviewees who were "very much" bothered is shown in Figure 10. Comparison of Figures 9 and 10 shows that the "very much" annoyed interviewees showed relatively little habituation, and the habituation was concentrated in the middle groups, between the two extremes of "not at all" annoyed and "very much" annoyed.

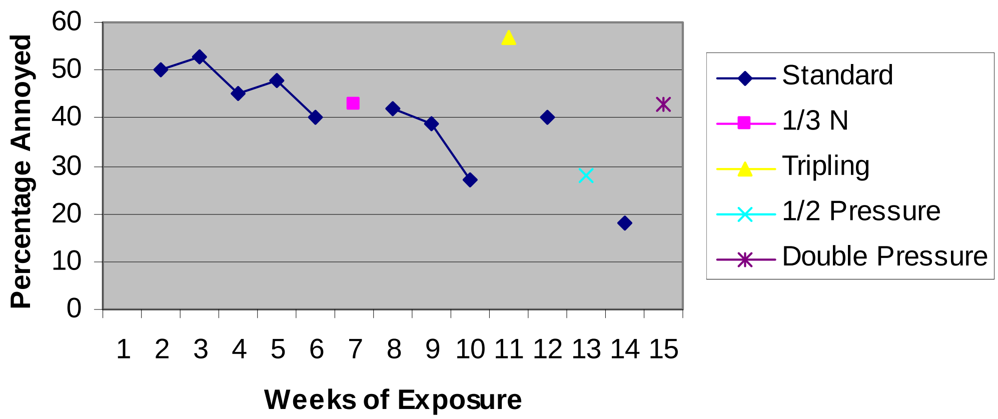

Figure 9. Aerial blasts — all "annoyed" persons (author's adaptation from Webb and Warren 1962).

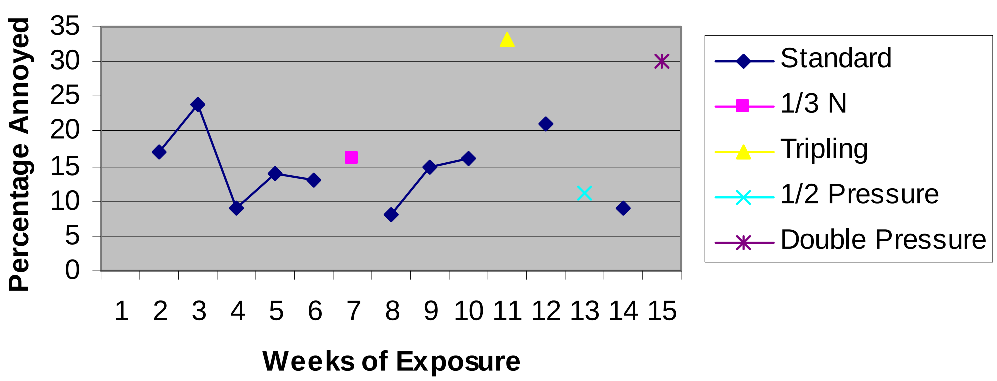

Figure 10. Aerial blasts — all "very much annoyed" persons (author's adaptation from Webb and Warren 1962).

During the tenth week, the number of explosions was tripled, and the percentage "not at all" annoyed dropped to 43%. When the standard exposure was reinstated in the eleventh week, along with a change to an evening schedule (1800 – 2100), the percentage "not at all" annoyed increased to 60% and in the twelfth week , when the peak pressure was halved, the "not at all" annoyed increased to 72%. By the thirteenth week, with the normal time and standard exposure, the percentage of "not at all" annoyed was the highest it had been at any time during the study (82%). Following a doubling of peak pressure level in the last week, the number of "not at all" annoyed retreated to 57%.

Comparing across the 13 weeks, between the first presentation and the last presentation of the standard exposure, it appears that at least 32% of the interviewees habituated to the blasts. As plotted in Figure 9, the percentage of "annoyed" persons bears more than a passing resemblance to a classic habituation curve. At the same time, the "most annoyed" people have difficulty in habituating, and the downregulation of response is minimal for this more extreme group.

The response to increases in level or number provides support for the equal energy principle, which is the foundation of most environmental noise assessment procedures. The percentages of increases, after an increase in cumulative daily exposure, a tripling of blasts (5 dB increase in daily Leq) and a doubling of peak level (6 dB increase in daily Leq) were about the same. In this regard, the evidence for the relevance for equal energy is comparable to the evidence used by the USEPA to establish the acceptable limit for sonic boom exposure, which also incorporates equal energy (USEPA 1974). That evidence came from a study of sonic boom exposure over Oklahoma City in which the level was "ramped up" over a period of months (von Gierke and Nixon 1972).

Case Study 2: Some blasts below threshold of detectability

The second case study is a survey of 966 residents living as close as 5 miles, and up to or beyond 20 miles, from a demolition ground operated by Naval Ammunition Depot Crane in Crane, Indiana. This study was conducted by Mark R. Green, an employee of the Research and Development Department of NAD Crane and published as Research and Development Technical Report (RDTR No. 261) on 30 September 1973 as an unclassified, limited-distribution document. * Under the provisions of the limited

* A copy of the original 61-page report is available upon request to ERDC-CERL, Installations Division, Ecological Processes Branch, PO Box 9005, Champaign IL 61826-9005.

distribution, the document was released to the Army by the Commanding Officer of NAD Crane in 1977, in support of the standing down of NAD Crane and the standing up of Crane Army Ammunition Activity.

From a companion study, "The Sonic and Seismic Effects of Demolitions at NAD Crane" (Hitchcock and Montgomery 1975), it is known that the demolition ground operated with up to 500 lb explosive per pit with minimum burial of 6 to 10 feet to reduce fragmentation. No information is available on the number of pits per day, or the number of days in the year, during which the demolition range was in operation.

Table 6. Perceptions of blast noise among interviewees living various distances from a demolition ground at which charges of up to 500 lbs weight were detonated (Dept. of Navy 1973).

Distance	Percent Hearing Blasts	Percent Reporting Damage		Percent Bothered
		% Minor	% Major	
5 mi	100.0	7.1	21.5	28.6
10 mi	93.5	17.7	3.2	32.2
15 mi	84.6	2.4	1.4	17.8
20 mi	72.5	1.3	1.6	14.2
Over 20 mi	26.7	0.3	0.3	6.6

Table 6 provides key statistics about the perceptions of interviewees living at different distances from the 500 lb explosions. Two variables, the percentage of people who reported hearing blasts and the severity of property damage, decline with increasing distance from the range. In contrast, the percentage of people reporting being bothered by the noise actually increased slightly with a doubling of distance from 5 to 10 miles.

Why should a group of residents who are receiving a lower cumulative blast noise exposure report the same or higher annoyance than residents receiving a higher cumulative exposure? A possible answer can be found in the statistics of blast noise propagation.

With increasing distance, the standard deviation of blast levels from a fixed explosive weight increases (Schomer and Luz 1994). Consequently, the level of the most intense blast which can be measured at the more distant location does not decrease by the same number of decibels as the level of the median blast.

If, as suggested by the analysis of Rylander and Lundquist, the annoyance of blast noise is tied to the number of events exceeding some threshold of observation, then the number of high level events at 10 miles may not be dramatically different from the number at 5 miles. At the same time, with many more events falling below the threshold of detectability at 10 miles than at 5 miles, residents have less opportunity to habituate to blasts.

As was observed in Case Study 1, some of the people living within 5 miles reported not being bothered by the noise (71%). Of the 29% who were bothered, all reported some degree of damage to their homes. Although the report's author did not state whether demolitions had actually damaged these homes, it is common for people living in houses exposed to peak pressure levels, as high as those for the 5-mile group, to believe that minor damage such as cracks in plaster walls, loosened or broken window pains, or shifts in foundation, is caused by the blasts. Given that the study of noise annoyance is a study of psychological processes, however, the question of whether the damage was actual or supposed is not particularly relevant to the current discussion.

People living 5 miles from the demolition ground received a higher Leq than people living at 10 miles. It is conventional to say that noise levels decrease by 6 dB for every doubling of distance, meaning the 10-mile group was receiving at least 6 dB less Leq than the 5-mile group.* Yet, the 10-mile group was more bothered. This observation is consistent with a psychological theory which is complementary to habituation theory - Adaptation Level Theory (ALT) (Helson 1964).

Whereas habituation theory describes behavior observable from outside an organism, ALT describes behavior observable from inside the organism – the subjective experience of sensory stimulation. ALT uses the logarithm of the cumulative exposure to define the adaptation level which an individual uses to judge new stimuli. The more stimulation the organism receives, the greater the adaptation level, and the less likely that future stimulation will exceed that adaptation level.

According to Helson, an organism's adaptation level can be estimated from the logarithm of the cumulative exposure. Thus, the people living at 5

* The value of 6 dB is used here solely for purposes of argument. It is likely that if the blast exposure had been modeled using the USA-CERL computer model for range noise, BNOISE, the difference would be more than 6 dB.

miles, where the logarithm of cumulative exposure was greater than for the people living at 10 miles, would be expected to have a higher adaptation level than their more distant neighbors. That higher adaptation level then would explain why the 5-mile residents could be expected to judge the most intense blasts heard at their location to be less loud than blasts of that same intensity which were experienced by people living at 10 miles.

Case Study 3: Sleep disturbance

Case Study 3 is a laboratory comparison by Dutch researchers of sleep disturbance from three digitally-reproduced sources: single shots of a rifle or machine gun, volley shots of a rifle or machine gun, and aircraft flyover (Vos and Houben 2007). The study involved 22 subjects who slept in a motel-like setting for 18 nights. Figure 11 shows the probabilities of awakening to each sound.

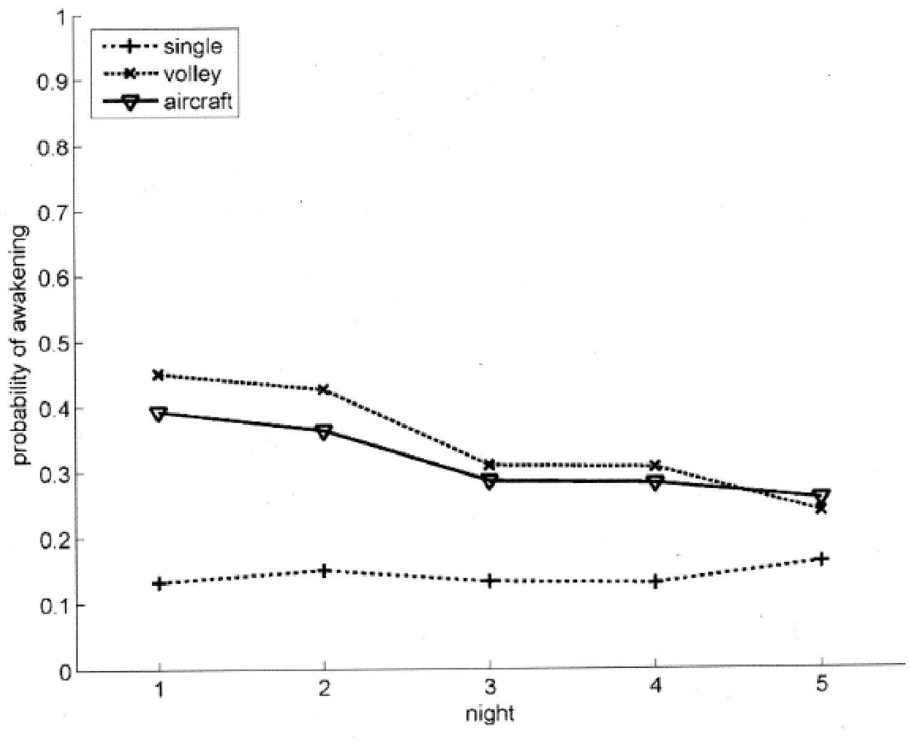

Figure 11. Probability of awakening from single and multiple weapons shots as a function of time (Vos and Houben 2007).

Two key findings from this study were (1) a higher incidence of awakening to volleys of shots than to single shots, and (2) no habituation of awakenings to single shots. This pattern is consistent with the dual process theory of habituation under the assumption that sensitization from a single shot was large enough to retard habituation.

The observation that awakening is less likely for shorter-duration sounds than for longer sounds is not new; Thiessen published this observation over 30 years ago (Thiessen 1978). He was working with 29-sec tape recordings of truck noise, in which the maximum level was 25 dB above the background. This very noticeable sound was presented seven times a night over 24 successive nights. Under these conditions, the probability of awakening dropped to half value in about two weeks.

In addition, Thiessen presented a figure in his 1978 study that compared the probability of awakening to his recorded truck sounds against the findings of others who were working with sonic booms. As in the current Dutch study (Vos and Houben 2007), Thiessen found there were fewer awakenings to short impulsive sounds (sonic boom) than to longer duration sounds (29-sec truck noise recording).

Also in the Vos and Houben study, awakenings to isolated impulsive sounds (e.g., simulated sonic booms) proved to be resistant to habituation. In the first of two studies from the Stanford Research Institute, Lukas and Kryter found some habituation to booms of 0.6 to 0.8 psf, but no habituation to booms of 1.6 to 2.1 psf (Lukas and Kryter 1970a).

In a second study, Lukas and Kryter found habituation among two older men (age 69 and 72 yrs) who were exposed to three blasts per night, at 0.63 psf, over a period of 10 nights. The habituation manifested itself as an adaptation (apparent in Stage 2 sleep) during the subsequent six nights of exposure, in which some of the booms were at 0.63 psf and others were at 1.2 psf (Lukas and Kryter 1970b). Comparable habituation was not found among younger subjects. Collins and Iampietro (1972), working with simulated booms at 1.0 psf (127.6 dB outdoor/109.9 dB indoor), found no evidence for habituation in the electroencephalogram (EEG) indicators of awakening for younger subjects.

Evidence that the fast rise-time impulses elicited more sensitization than the slow rise-time aircraft sounds comes from Vos and Houben's latency data. Their median awakening latency for shooting sounds, whether single shots or volleys, was about 7 sec. Their median latency for the aircraft sound was about 18 sec. In the acoustic startle response literature, shorter response latencies are generally attributed to a greater degree of arousal. With impulsive sounds repeated in rapid succession, the sensitization from each impulse accumulates to result in more awakenings than from a single shot.

Case study 4: Habituation to high numbers of blast events (comparison across groups)

The fourth case study is the previously-referenced Swedish postal questionnaire of 1,483 randomly selected Swedish residents living in 20 areas around eight ranges with heavy weapons training (Rylander and Lundquist 1996). As noted earlier, very few people were annoyed in areas where the worst-case levels were below an SEL of 95 dBC. The highest amount of "very annoyed" interviewees was 8% in areas where the worst case never went above an SEL of 90 dBC. For those living in areas where the worst-case level was above an SEL of 95 dBC, however, the annoyance jumped dramatically (more than 30% "very annoyed") when the annual number of shots exceeded 200.

As was shown by Figure 8, the percentage of "very annoyed" begins to decrease as the annual exposure exceeds 5,000 shots. This observation is consistent with the hypothesis that exposure to a large number of shots will lead to habituation among a certain segment of the exposed population (Presumably, there still is a small percentage of the exposed population which is highly-resistant to habituation, as was found in Case Study 1.) In terms of Helson's ALT (discussed earlier under Case Study 2), the people exposed to a large number of shots at levels above 95 dB CSEL have more opportunity to adapt to the sounds, and, consequently, are not as reactive to individual shots as are people who have fewer opportunities to adapt.

It should be noted that the Rylander and Lundquist data are cross-sectional, and, for this reason, provide relatively weak, indirect evidence for the role of habituation and adaptation. The best kind of data would be longitudinal data in which researchers measure the sound level of each shot experienced by the interviewee and collect an interviewee's rating for the annoyance of (1) each shot, (2) the cumulative annoyance of all the shots experienced during the day, and (3) the cumulative annoyance for larger periods of exposure, such as the past week, month, or year. A longitudinal study of blast noise annoyance is not available in the published literature, but such a study is planned as part of the previously referenced SERDP project. Results from three published studies indicate that this type of longitudinal study is feasible for the following reasons:

1. Luz et al. (1994) demonstrated orderly judgments of the annoyance from individual blasts, as experienced by residents near Army firing ranges.
2. The ability of noise-exposed interviewees to report orderly data on their daily annoyance was established by Fields and Powell (1987) in a controlled study of helicopter noise. In that study, the interviewees were exposed to daily numbers of helicopter flyovers ranging between 1 and 32 per day. This daily range of intrusive sounds approximates the numbers of daily blasts experienced by people living near military firing ranges.
3. The ability of interviewees to report orderly data on annoyance during the past week and past month was established by Fidell et al. (1985). In that case, the sound sources were aircraft flyovers with people being interviewed at different periods before and after the closure of runways or opening of new runways.

Case study 5: Habituation to high average energy (DNL), (comparison across groups)

Case Study 5 was conducted to test a hypothesis developed from research conducted jointly between USA-CERL and the Institute for Noise Abatement in Duesseldorf, Germany. This study was the third study of the annoyance of heavy weapons noise conducted in Germany by the Buchta team (Buchta and Vos 1998). As part of the study, data were collected in 1991 at 17 noise zones around the German military facilities in Bergen and Munster. A key figure from this study is reproduced here as Figure 12.

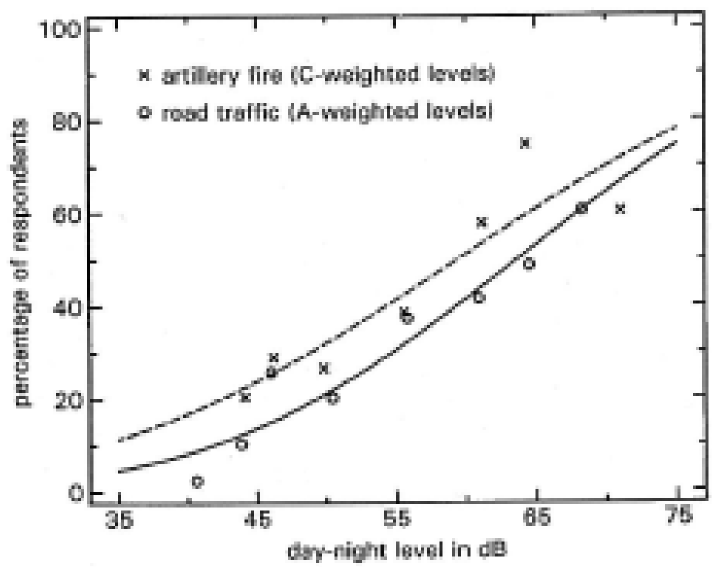

Figure 12. Percentage of respondents describing themselves as "clearly or highly annoyed" as a function of the yearly average C-weighted level for the shooting sounds and as a function of the A-weighted day-night level for the road-traffic sounds (Buchta and Vos 1998, Fig. 5).

In Figure 12 the annoyance of traffic noise (as measured with A-weighting and presented as DNL) is compared with the annoyance of blast noise (as measured with C-weighting and presented as DNL).* The open circles show the percentage of interviewees who described themselves as "clearly or highly annoyed" in response to various levels of traffic DNL. As would be expected, the highest intensity of traffic noise was associated with the highest degree of annoyance. However, this expectation did not hold up for blast noise (shown by "x" in Figure 12). The highest blast noise DNL was associated with a lower degree of annoyance than the second highest DNL. This downturn at the highest exposure level mirrors the downturn reported by Rylander and Lundquist. As noted above for the Rylander and Lundquist data, the data from Buchta and Vos are cross-sectional, and the evidence for habituation is indirect.

* The C-weighted DNL presented in Figure 12 was adjusted by use of a method for equating the growth of loudness of continuous noise with the growth of loudness from weapons noise. The observation that the growth of loudness and/or annoyance for these two categories of noise is different was first observed in a CERL-funded study (Young 1976). The study found that a 10dB increase was needed to generate a doubling of the subjective annoyance reported for aircraft flyover noise, but only a 6.7 dB increase was needed to generate a doubling of annoyance for simulated artillery noise. Because differences in growth of loudness is not central to the current discussion, it, is not discussed further in this report.

5 Conclusions and Recommendations

Summary

Review of the available publications on the annoyance of impulsive noise shows that habituation is an important variable in predicting whether a particular community will be significantly annoyed by a specific exposure to weapons noise. The importance of habituation in understanding the annoyance of weapons noise stands in contrast to the insignificant role which habituation plays in understanding the annoyance of highway, railroad and airport noise. A useful theory for understanding habituation to weapons noise is the dual process theory published by Groves and Thompson (1970). This theory assumes that habituation can be masked by an independent, intensity-dependent process (sensitization), which occurs in different sets of neurons than does habituation.

Conclusions

The likelihood that the annoyance of high-intensity blasts is influenced by dual processes, habituation and sensitization, has important implications for the treatment of *in situ* annoyance data that is collected from persons experiencing impulsive sounds while going about normal activities in their own home. The self-reported annoyance of a person who notices a weapons blast is modulated by past experience with weapons blasts. Cumulative habituation from previous exposures to blasts (at either the same or other levels) could be less if the person reporting the annoyance has the nervous system of an augmenter, rather than the nervous system of a reducer.

For example, reducers, who can be expected to habituate to intense sounds more easily than augmenters, would be expected to rate the first intense blast of the day as more annoying than a subsequent blast of the same intensity. Augmenters would be expected to rate the subsequent blast equally as annoying as the first blast of the same intensity. The augmenter might even rate a subsequent blast as more annoying.

Such contingent relationships are difficult to describe using typical multivariate statistics. If conventional statistics are applied to such data, the dynamics of habituation and sensitization end up in the “garbage can” of "error variance," with diminished correlations between the subjective judgments and acoustical variables.

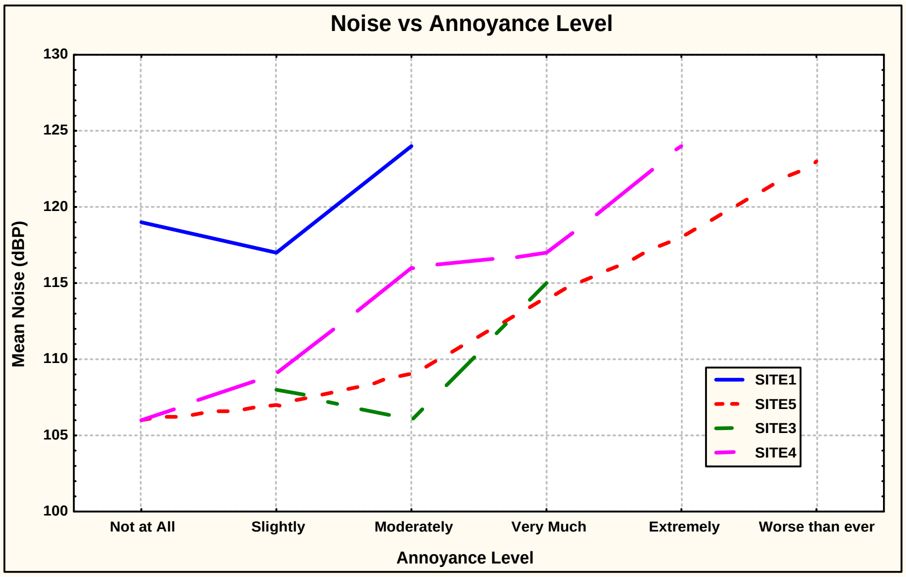

Figure 13. Annoyance judgments of individual blasts made by homeowners exposed to blasts from heavy weapons firing (Luz, Lewis, and Russell 1994)*.

Figure 13 provides an example of how individual differences between augmenters and reducers might play out during an *in situ* study of blast noise annoyance. The four curves summarize the annoyance judgments of four individuals, each of whom was asked to judge the annoyance of blasts from Aberdeen Proving Ground, as experienced in their homes (Luz, Lewis, and Russell 1994).

Each data point gives the energy average of blasts which that individual tagged with an annoyance label. Two of those individuals used the full five-point annoyance scale requested by the research team, but one of those two people decided that one particular blast was so unusually annoying that she added another category. One individual fit all of her judgments into a three-point scale of "slightly," "moderately" and "very much," while a fourth fit his judgments into a three-point scale of "not at all," "slightly," and "moderately." About the same level at which the male homeowner judged blasts to be "moderately" annoying (124 dB), the female homeowner categorized the blast as "worse than ever" (123 dB).

* In the original study, there were eight numbered sites, but only the four sites shown had occupants present during the day.

Recommendations

1. Do not pool judgments of the annoyance of blasts of different intensities across subjects (for data from *in situ* blast and sonic boom noise studies). Statistical techniques should be developed to treat each individual as a unique, non-linear system in which habituation and sensitization are treated as independent processes.
2. Researchers should rethink plans to omit certain questions they feared would be considered personal or psychological in nature. (This recommendation is specific to the *in situ* blast annoyance study to be conducted as part of the ongoing ERDC–CERL, SERDP-funded project focusing on evaluating responses to military noise. The research team's decision was based on time burden considerations.) However, without information on where the *in situ* subjects fall along the reducer-augmenter dimension or the interrelated extraversion-introversion dimension, the research team will be trying to interpret the *in situ* data without an important variable.
3. The research team should request a modification of the protocol for the *in situ* study, to allow the option for subjects to be voluntarily interviewed with the Vando reducer-augmenter scale (Vando 1969) and the extraversion dimension of the Eysenck Personality Inventory (Eysenck and Eysenck 1985).
4. Because the approval process for a change in questions is lengthy, the research team should plan to administer these two paper-and-pencil tests after the *in situ* data have been collected. Since some subjects may be wary about giving psychological information to government representatives, the research team should be prepared to lose some of the subjects in this additional study.
5. A model of annoyance should be used that is compatible with the dual process theory of habituation, specifically that proposed by Botteldooren and colleagues (Botteldooren et al. 2008). A schematic diagram of this model is provided as Figure 14. Two loops in this model, “bottom-up attention” and “sensitivity control” would appear to be amenable to the sensitization and habituation processes.

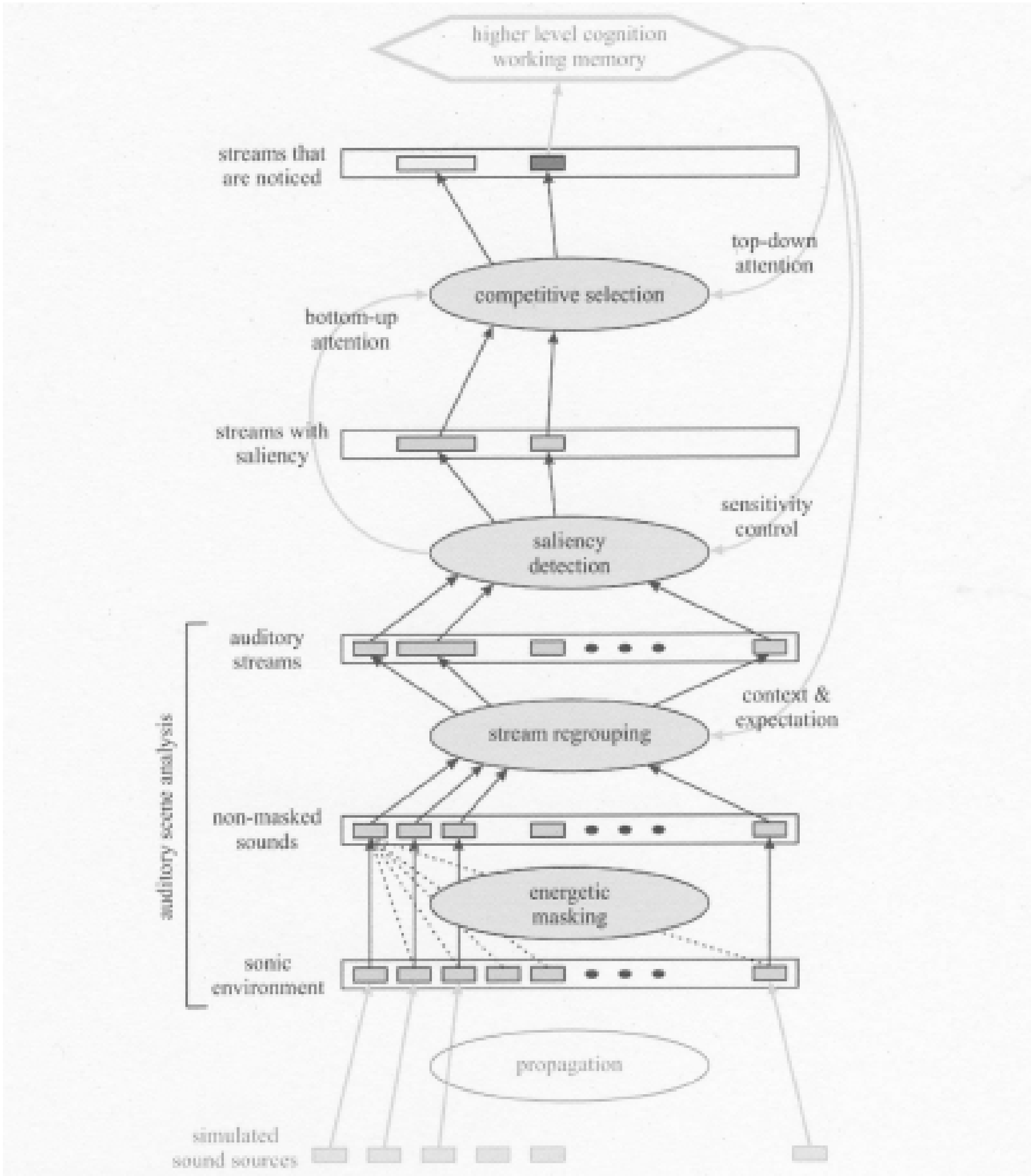

Figure 14. The Attentional Model of Noise Annoyance (Botteldooren et al. 2008).

6. It is recommended that future versions of the BNOISE model (used for predicting heavy weapons exposures in the vicinity of Army training areas) use an algorithm based on the probability distributions (mean and variance), in order to simulate the statistical distribution of blast levels at each receiver point. (Currently, the model calculates the average level of each type of weapons blast at each point on the map grid for the area under consideration. The output is in the form of the cumulative exposure at each point on the map grid.)

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Abbreviations and Acronyms

Term	Spellout
ADNL	A-weighted DNL
ALT	Adaptation Level Theory
ANOVA	Analysis of variance
ANSI	American National Standards Institute
ASEL	A-weighted sound exposure level
ATC	Army Training Center
BNOISE	Blast noise computer program developed by CERL
CDNL	C-weighted DNL
CEC	Connected Energy Corporation
CERL	Construction Engineering Research Laboratory
CN	Installation Division of CERL
CN-N	Environmental Branch of CN
COMT	Catechol-O-methyltransferase encoding (genetics)
CSEL	C-weighted sound exposure level
dBA	Decibels, A-weighted
DNL	Day-night level
DR	Defense Response
EEG	Electroencephalogram Test
EOD	Explosive ordinance disposal
ERDC	Engineer Research and Development Center
FAA	Federal Aviation Administration
GSR	Galvanic skin response
HR	Heart rate
ISO	International Organization for Standardization
ISVR	Institute for Sound and Vibration Research
LAE	Sound exposure level
LEQ	Equivalent level
McAAP	McAlester Army Ammunition Plant
NAD	Naval Ammunition Depot
NAS	Naval Air Station
NASA	National Aeronautics and Space Administration
NATO	North Atlantic Treaty Organization
NSWC	Naval Surface Warfare Center
OR	Orienting response
PNSE	Point of Noise Subjective Equivalency
PRINCAL	PRINcipal Components Analysis by Alternating Least
PTSD	Post-traumatic stress disorder

Term	Spellout
RDTR	Research and development technical report
RF	Radio frequency
SCR	Skin conductance response
SEL	Sound exposure level
SERDP	Strategic Environmental Research and Development Program
SPL	Sound Pressure Level
SR	Startle response
SRI	Stanford Research Institute
TDR	Transient detecting response
USACERL	U.S. Army Construction Engineering Research Laboratory
USAEHA	U.S. Army Environmental Hygiene Agency
USAREUR	U.S. Army in Europe
USEPA	U.S. Environmental Protection Agency

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14. ABSTRACT

personnel must consider the effect of the noises their activities produce. Understanding and predicting how people react to such common military noise as gunfire or explosive blasts is important, since nearby civilian populations and their opinions of military operations can affect future military operations and facility expansions. The problem this report addresses is determining those factors which are the best predictors of whether someone will be annoyed by noise. To better select the most valuable predictors for annoyance to military noise, a review of published international studies on the subject was done. One possible predictor is a physiological process known as "habituation," in which the brain stops responding to repeated stimuli. This review then goes beyond habituation to include the roles of the dual process theory and individual sensitization, both of which can influence reported annoyance. This work concludes with recommendations of what military planners and their research teams should consider in order to obtain the most reliable results from future studies of annoyance to military noise. Those recommendations include specific suggestions for designing new surveys that better explain relationships between individual characteristics or situations, and the same individual's annoyance to noise.

15. SUBJECT TERMS
noise, military noise, blast noise, military training, human response

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